10-10-2017

Mobile Data Roaming and Incentives for Investment in Rural Broadband Infrastructure

James Prieger
Pepperdine University, james.prieger@pepperdine.edu

Pepperdine University School of Public Policy

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Professor of Economics and Public Policy

October 10, 2017

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I. Introduction[1]

Mobile broadband Internet access is highly important to the American economy and millions of users. There were almost 200 million mobile broadband connections by the end of 2013 in the United States, far more than the number of fixed broadband connections (FCC, 2014a, Table 1). The economic activity created by the provision and usage of mobile broadband is sizeable, and has been documented at the national level (Gruber and Koutroumpis, 2011; Thompson and Garbacz, 2011; Katz, 2012) and specifically for rural areas (Whitacre, Gallardo, and Strover, 2014). The benefits of mobile broadband—and indeed the entire broadband ecosystem—depend on investment in deploying and upgrading network infrastructure by broadband providers. Thus investment in mobile wireless infrastructure plays a vitally important role in sustaining the growth of the industry and the economy. Investment is also the means by which robust facilities-based competition among mobile broadband providers develops, to the benefit of consumers who enjoy more options, greater wireless coverage, and lower prices.

The significance of wireless investment for America implies that there is a high opportunity cost to pay in terms of the forgone benefits when investment is discouraged. Each dollar not spent on investment destroys more than a dollar's worth of economic output and GDP, as well as lowering earnings and employment, due to the interconnected nature of the economy. Given the high opportunity cost of forgone investment, it is important to examine public policy affecting the mobile broadband industry to ensure it does not diminish the incentives to invest. Infrastructure does not grow by itself. Instead, the network deployment underlying today's broad coverage for LTE mobile broadband is the result of the more than \$170 billion in wireless capital expenditure (capex) the providers have invested since 2010.[2] Preserving incentives and lowering barriers to invest thus are paramount.

Since broad network coverage is a valuable aspect of mobility for many customers, roaming—the process by which one wireless provider uses another provider's network—has always played an important role in mobile communications. Roaming arrangements allow a provider to offer service to its customers when they travel to areas where the provider holds no spectrum licenses, for example, or to serve customers temporarily while it builds out its infrastructure in areas it does hold licenses.

[1] The author can be contacted at james.prieger@pepperdine.edu.

[2] Data from Credit Suisse (2015), FCC (2015b), and the major carriers' 4Q 2015 earnings conference calls indicate that wireless capex from mobile voice and data service providers in the United States totaled about \$171.5 billion over 2010-2015.

Current federal policy toward mobile data roaming, however, has the potential to discourage investment in infrastructure, and indeed appears to have done so. In the last decade, public policy regarding mobile roaming has moved from allowing great leeway in the terms and conditions reached in private agreements between providers. Instead, today's rules grant ever more bargaining power and lower rates to the party requesting roaming from the carrier that actually deployed the infrastructure. The particular policies of the Federal Communications Commission (FCC) toward mobile data roaming are reviewed below. The policies can be seen generally as constituting a form of *access regulation*. With access regulation, rules are promulgated to mandate granting rivals access to a carrier's network infrastructure. Access regulation enables (artificial) service-based competition, as opposed to actual facilities-based competition in which both parties invest in building competing physical networks.

The problem with access regulation in general and mobile data roaming in particular is that mobile broadband providers with weaker resources or more risk aversion are tempted to delay deploying their own infrastructure (Bauer, 2010). Firms with resources available for investment have incentive to delay, since part of their expenditure will accrue to the benefit of their rivals. That is, "host providers may have a disincentive to invest in their networks if other providers can 'free-ride' on their investment via roaming"—a quotation taken (in irony, given the FCC's later decisions) from the FCC's own data roaming order.[3] The result may be that "industry may invest less on a per capita basis and consumers may consequently experience slower improvements of the price/quality ratio over time" (Bauer, 2010, p.76).

The investigation here of the consequences of policy in the United States toward mobile data roaming begins in the next section with discussion of the general importance of investment in infrastructure for mobile broadband. Part A of section II reviews the importance of mobile broadband for rural areas, and part B quantifies the opportunity cost of a dollar not invested. Section III contains an analysis of the disincentivizing impact of access regulation. General knowledge about access regulation, investment, and the diffusion of broadband is reviewed in part A of section III. Part B presents a review of FCC policy toward data roaming and an assessment of the particular negative consequences for the economy. The analysis indicates that the poor incentives created by liberal data roaming policy may have cost the economy an estimated $20 billion in output, $11 billion in GDP, $6 billion in earnings for workers, and 134,000 jobs. Under some alternative assumptions, these opportunity costs are even larger.

II. The impact of investment in mobile telecom infrastructure

Investment in the mobile broadband industry contributes to economic performance through direct and indirect channels. Broadband investment boosts growth directly through the obvious impacts of the money

[3] FCC (2011a), footnote 76.

spent on the infrastructure and the employment required to deploy it. There are several indirect effects of the investment on the economy, however. Most immediately, the direct spending on infrastructure and employment creates ripple effects in the economy. When mobile broadband providers purchase additional equipment, the suppliers of the inputs increase their own demand for the inputs needed to produce their goods. Similarly, the extra earnings in the pockets of workers stimulate consumption in the economy at large. Thus, each dollar spent on infrastructure investment creates more than a dollar's worth of economic activity.

Mobile technology also induces economic growth indirectly through the positive externalities provided by mobile telecommunications as a general purpose technology. Mobile broadband Internet access and usage is an increasingly essential part of the national and global information economy. Broadband is an example of *general-purpose technology* (Prieger, 2013). A general-purpose technology is pervasive, has high potential for technical improvements, is greatly useful to businesses, and can be employed to increase the productivity of R&D in downstream sectors (Bresnahan and Trajtenberg, 1995). A general-purpose technology such as broadband spreads throughout all aspects of the economy and creates productivity gains in many industries, within and without the broadband ecosystem. A general-purpose technology like mobile broadband is thus important to the economic health of a region and the national economy.

In this section, the links between broadband investment and the economy are reviewed. Section A contains a general discussion of the importance of mobile broadband and investment for rural development. Direct and indirect impacts, including non-economic effects, are presented and discussed. Section B turns to measuring the opportunity costs of not investing in mobile broadband. Conventional methodology from the United States Bureau of Economic Analysis is adopted to quantify the economic impact of mobile broadband investment.

A. Mobile broadband is important for rural development

Since data roaming is most common in rural areas, the focus of the following discussion will be on rural areas. Broadband brings benefits of many kinds to rural America. This section discusses the economic and other impacts of investment in mobile broadband and usage of the service.

1. Economic impacts of investment in broadband

The exploration here of broadband's impact on the economy begins with its direct impact on GDP. Next, evidence on the overall impacts on GDP and growth is presented. An examination of the relationship between broadband and employment concludes this section. Given the relatively recent explosion of mobile broadband usage, many of the studies discussed here do not separate mobile broadband from fixed Internet access. However, given the predominance of mobility in the broadband marketplace in recent years, the results of these studies are applicable to mobile broadband as well. Many studies document a positive association between broadband availability and usage and economic growth (Holt and Jamison, 2009). Although nearly all studies on the subject conclude that broadband is important for economic growth, different studies come to widely varying estimates of the impact due to differences in methodology and the scope of impacts considered.

Private investment in broadband appears directly in GDP.[4] Given the huge amount that broadband providers have invested in the United States, the direct contribution of infrastructure investment is sizeable. Since 1999, broadband providers in the United States have invested over 1.2 trillion dollars in private capital expenditure on fixed and mobile broadband.[5] Since 2009, investment in network infrastructure in the nation has averaged about a half of a percent of GDP. In 2014, American broadband providers invested $78 billion in total infrastructure and $32 billion on wireless broadband capex.[6] These investments have been required to expand steadily the availability and speed of fixed and mobile broadband service offered to consumers.

Broadband Internet access also appears in GDP as a consumer and business service. A conservative assessment of the direct impact of broadband Internet access on GDP begins with accepted methodology from the same agency that computes the official estimates of GDP for the United States. Greenstein and McDevitt (2011, 2012) perform two such studies to show that the direct impact of broadband Internet access as a consumer service was approximately $8.3 to $10.6 billion of new GDP in 2006 ($9.8 to $12.5 billion in 2015 dollars). For 2010, they find that there was an additional $9.1 billion in new consumer surplus created by broadband (net of what would have accrued with earlier technology) that does not show up in GDP. Similar calculations show that by 2010, broadband is conservatively estimated to have created $9.1 billion ($9.9 billion in 2015 dollars) in new consumer surplus in the US, leading to a total "broadband bonus" for the economy of $39.8 billion ($43.2 billion in 2015 dollars).[7] After accounting for quality improvements in broadband, mainly in the speed of service, the estimate of consumer surplus rises to $95 billion and the overall broadband bonus to $126 billion ($103 and $136 billion in 2015 dollars, respectively). Other estimates that consider indirect impacts or that do not carefully net out the benefits from replaced technology often arrive at figures that are much higher.

Apart from the national accounting approach, econometric estimates allow a more inclusive assessment of how mobile broadband increases national growth. Such

[4] The main components of GDP as calculated for the official estimates are consumption, investment, government spending, and net exports. GDP is a gross measure, and therefore investment is counted (or more properly, gross private domestic investment) includes both investment in new fixed assets as well as investment to replace depreciated assets (BEA, 2015). Due to leakages from imports, a dollar of private investment may add less than a dollar to GDP.

[5] The data on capex are from USTelecom (www.ustelecom.org/broadband-industry-stats/investment/historical-broadband-provider-capex), who in turn used a variety of industry sources.

[6] The total figure is from USTelecom (see previous footnote); the wireless capex is from Credit Suisse (2015).

[7] The broadband bonus is calculated as broadband revenue less cannibalized dial-up revenue plus new consumer surplus.

studies can account for all the ways broadband affects the economy, albeit without necessarily identifying the paths between investment and final economic outcomes. In one of the studies looking at mobile broadband in particular, Gruber and Koutroumpis (2011) find a sizable positive impact of mobile infrastructure on GDP across many years and countries. The authors calculate that mobile telecommunications contributed 0.4 percentage points to GDP growth in high-income countries like the United States. Thompson and Garbacz (2011) also found econometric evidence that mobile broadband has an important effect on GDP—in fact, much more important than that of fixed broadband. Gruber and Koutroumpis (2011) also find that mobile broadband infrastructure increases output per worker-hour, contributing 0.3 percentage points to annual productivity growth in countries with the highest mobile usage penetration (such as the United States). Another notable finding from their study is that there are increasing returns in the impact of mobile infrastructure deployment. Thus, investment in mobile broadband infrastructure in rural areas may yield more than proportional increases in income and employment growth.

Broadband can be similarly important for creating and sustaining employment. As with GDP, direct and indirect impacts can be distinguished (Katz, 2012). The construction of broadband networks creates jobs directly through demand for labor to deploy the infrastructure and the labor used to manufacture and transport the equipment. Additionally, investment creates further indirect employment in the sectors further upstream than the direct suppliers of the inputs. Least proximately, but still directly related to broadband investment, the extra wages generated create additional consumer spending, which can induce further usage of labor throughout the economy. Several studies in recent years calculate employment multipliers, defined in this context as the ratio of total jobs created (direct, indirect, and induced) to direct jobs created from broadband investment. Atkinson, Castro, and Ezell (2009) find an employment multiplier of 3.6 when jobs from all three sources mentioned above are included. This implies that for each job created directly the additional demand for labor to build the network, there are 2.6 other jobs created by the additional demand in upstream industries and induced by additional consumer spending. Katz and Suter (2009) found a slightly smaller estimate of the comparably defined multiplier, 3.4.

For the overall impact of broadband on employment, including the three channels from investment described above but also impacts from businesses, industries, and workers made more productive by broadband, we turn to econometric studies. Reviews of the literature show that several studies find positive links between broadband availability and increased employment, particularly during the recent recession years when there was significant slack in the economy (Katz and Suter, 2009; Holt and Jamison, 2009; Katz, 2012). More recently, Jayakar and Park (2013) find that US counties with better broadband availability had lower unemployment rates in 2011, even after controlling for other factors. Investment in mobile broadband infrastructure thus has clear potential to improve the outlook for employment in regional and the national economies.

While the employment studies discussed above were national in scope, a recent study by Whitacre, Gallardo, and Strover (2014) examined the impacts of broadband on rural areas in particular. By carefully matching counties with a high level of broadband adoption to observably similar counties with lower adoption, the authors are able to isolate the effect of adoption on how employment and other economic outcomes changed between 2001 and 2010. The study is notable both for its focus on rural counties and for having a credible econometric approach to identify the causal effect of broadband on employment. They find that non-metropolitan counties with high levels of broadband adoption (defined as adoption rates above 60%) had significantly greater reductions in the unemployment rate when compared with otherwise similar counties with less adoption. They also find that non-metropolitan counties with low levels of broadband adoption (below 40%) had significantly lower increases in employment levels, compared with similar counties with more adoption. The same study finds that broadband adoption in rural areas leads to higher increases in household income and greater growth in the number of businesses. Another notable result is that the availability of higher broadband speeds in non-metropolitan counties is associated with greater reductions in the poverty level compared to otherwise similar counties, which the authors interpret as "suggesting that broadband speed can potentially contribute to general community well-being" (p.1020).

These finding are generally in accord with an earlier study of rural areas using a similar matching methodology. Stenberg *et al.* (2009) paired each of 228 rural counties with a similar county that had low broadband availability. As in the study by Whitacre et al. (2014), the set of similar counties served as a control group. Over the years 2002-2006, the group of early-adopting counties experienced more job growth, particularly in the nonfarm sector. Broadband-available counties also had higher personal income and nonfarm earnings growth in some of the years. Not all of the apparent benefits of broadband Stenberg *et al.* found are statistically significant, but the counties with low broadband availability in 2000 never significantly outperformed the high availability group in any year of the study.

2. Other impacts of investment in broadband

Apart from the economic impacts of broadband investment and usage of broadband service discussed in the previous section, there are many other ways that investment in the availability of mobile broadband can improve the quality of life in rural areas. A few examples of benefits of broadband that are of particular interest for rural communities are increased community involvement, greater labor market opportunities through telework, and increased human capital through distance learning and telemedicine (Stenberg *et al.*, 2009).[8] The Internet can foster community interaction by lowering the cost of engaging in civic affairs and participating in community involvement. For example, it is much easier

[8] This section draws on the discussion in Prieger (2013; 2015).

for a rural resident to keep abreast of local land-use planning and issues by accessing information online than it would be to access county records in person. Stenberg *et al.* (2009), in their study of Internet usage in rural areas, cite several empirical studies finding that Internet use fosters civic engagement. While the path from Internet usage to outcomes of interest are not always clear, the data show that using broadband is positively correlated with higher levels of community involvement (Stern, Adams, & Boase, 2011). Stern and Adams (2010) suggest that better communication technologies (such as mobile broadband) lead to wider social circles and new ways to find information about civic participation. Such formation of "social capital" is most important in rural communities, where residents rely relatively more than in urban areas on local relationships with others to achieve personal and community goals. More recently, mobile broadband has been found to have a positive effect on digital citizenship, the engagement in online political and economic activities (Mossberger, Tolbert, and Anderson, 2014).

Broadband can also have a vital role to play in rural telework (Stenberg *et al.*, 2009, Morris and Goodridge, 2008). Many American businesses engage in global outsourcing for service support, yet customers are often dissatisfied with services outsourced to foreign countries. Couple these facts with survey results showing that almost two-fifths of rural residents are interested in working from home and would be open to telework. Finally, note that about three-fourths of businesses which outsource are interested in bringing some of those positions back to the United States if rural employees could fill the roles. For most such positions to be feasible, quality broadband connections would be required. Other, specifically mobile telework requires local rural employees in all cases. Examples here include sales and support staff of firms dealing with agribusiness. Of course, telework creates other benefits besides employment, including environmental benefits from decreased vehicular travel and reduced overhead and rents for employers (*Economist*, 2008).

Telemedicine is another beneficial service enabled by broadband in rural areas. Telemedicine gives rural communities access to some of the same health care infrastructure that urban areas enjoy. In one of the few empirical studies on the benefits of telemedicine, a case study of five rural communities in Oklahoma were found to have saved $3.5M in healthcare cost for teleradiology and telepsychiatry (Whitacre et al., 2009). Some of the economic benefits of telemedicine include reductions in transportation cost and improved productivity for rural residents, increased work for local medical labs and pharmacies, and cost savings to rural hospitals from outsourcing procedures via telemedicine.

Mobile broadband networks can play particularly important roles in telemedicine. One comprehensive review of economic analyses of heart failure monitoring systems found that all the studies concluded that telemonitoring was less expensive than usual care in a hospital, with a range of 2-68% cost savings, even before accounting for additional factors such as travel costs and a lower incidence of rehospitalization (Seto, 2008).

More and more e-health technology will rely on high-speed wireless networks, turning e-health into m-health. Some m-health applications such as downloading diagnostic data and lab results to smartphones are feasible today, as long as mobile broadband coverage is available in the area. Other m-health applications are just coming over the horizon of cost-effectiveness, such as personal networks of implanted or wearable body sensors. Since rural areas are more likely to be underserved by local healthcare facilities, leading to subpar healthcare (AHRQ, 2015), medical technology that allows remote monitoring or otherwise removes the limitations of distance in healthcare may greatly benefit rural communities.

B. The economic cost of discouraging investment

As discussed above, the total economic effects resulting from investment in mobile broadband are greater than the direct expenditure necessary to deploy the network. The U.S. Bureau of Economic Analysis (BEA) defines two types of spending multipliers (BEA, 2013). Type I multipliers account for the direct and indirect impacts of an increase in final demand (the wireless capex, in this case). The direct impact includes all the inputs purchased by the final-demand industry: communications equipment, construction, etc. However, those inputs themselves came from supporting upstream industries, and creating the inputs required additional purchases by those industries. Thus the capex expenditure in the ultimate industry results in further rounds of new spending[9] as the inputs used by the industries are linked to the outputs of the supplying industries. The sum of the direct and indirect impacts—the interindustry effect—composes the Type I multiplier. Type II multipliers add the induced impact of an increase in final demand to the interindustry effect. The induced impact arises from the additional household spending of workers whose earnings are affected by the investment and who spend that additional income in turn. The BEA calculates multipliers for regions, industries, and commodities based on regional input-output tables of the flow of goods and services in the economy.

The multipliers from BEA provide useful estimates of ratios of total changes to initial changes in spending on investment goods. However, it is important to understand on what the figures rely. The calculations assume there are no changes in commodity or labor prices resulting from the increase in investment. The estimates thus stop short of being a full macroeconomic multiplier, which would incorporate Type I and Type II impacts along with a host of other behavioral responses of consumers and firms to the investment spending. However, when there is slack in the economy (as has been generally true since the last recession), input-output multipliers and complete macroeconomic multipliers are more likely to be similar (BEA, 2013). The BEA multipliers provide a useful starting point to assess the initial and not-too-distant indirect effects of investment. Quantification of other indirect impacts, such

[9] The spending diminishes as it moves upstream from the originating industry because leakages occur through saving or spending outside the US economy.

as changes in the prices of investment goods due to increased demand or—even more distantly—changed prospects for employment due to the increased labor productivity, outsourcing, or e- and m-commerce that greater diffusion of broadband networks can (eventually) entail, would be highly speculative at best and is not pursued here.

The multipliers available to convert dollars of investment spending to dollars of total economic outcomes include those for output (sales), value added (GDP), and earnings. The output multiplier is the ratio of the total change in sales to the change in local output purchased by final users. Whereas the output multiplier is for gross sales, the value-added multiplier measures the total change in value added per dollar of investment. Hence, the value-added multiplier is comparable to increases in GDP. Since sales inevitably involve double-counting as commodities are passed up and down the supply chain, the GDP multiplier is smaller than the output multiplier. The earnings multiplier measures the increase in earnings per dollar of local output purchased through investment.[10] Similarly, the total employment change throughout the economy resulting from investment in mobile broadband is greater than the labor directly employed to design and construct the network. Employment multipliers estimate how investment spending translates into additional employment.[11]

Similar analyses using BEA multipliers to estimate the economic impacts of broadband investment in the United States have been conducted by Katz and Suter (2009), Atkinson et al. (2009), Eisenach, Singer, and West (2009), Crandall and Singer (2010), and Sosa and Van Audenrode (2011). These previous studies typically used only the employment multipliers and in some cases also the output multipliers.[12]

To make use of the multipliers, assumptions must be made as to how a dollar of wireless capex is spent. Previous studies made various assumptions but generally assume spending is split between wireless communications equipment and construction. Capital expenditure for purposes of investing in wireless infrastructure also includes expenditure on other items. Since backhaul is part of mobile broadband networks, and since backhaul often involves wired communications even when it is for wireless last-mile networks, another relevant commodity is fiber optic cable. Extending the capacity of wireless data coverage also requires deploying additional equipment on the backend, such as LTE equipment (i.e., the evolved packet core) and additional capacity in the wired network (routers, gateways, etc.) to handle the additional communications traffic. Finally, engineering services are required to design and implement the new network infrastructure

[10] Earnings include all additional wages, salaries, proprietors' income, and employer contributions for health insurance. Proprietors' income includes the net earnings of sole-proprietors and partnerships.

[11] The resulting number of jobs created may not all be full-time positions, since the employment data the BEA uses to analyze the employment requirements of the affected industries do not enumerate jobs in full-time equivalents (BEA, 2013).

[12] In some cases in the literature the output multiplier has been mischaracterized as a GDP multiplier. However, the value-added multiplier must be used to determine impacts on GDP (Bess and Ambargis, 2011, p.14). Gross output counts goods and services multiple times if they are used in the production of other goods and services.

and architecture. Depending on the breakdown of how an investment dollar is allocated to these items, the final multipliers can be calculated as weighted averages of the individual multipliers for the industries producing these commodities.[13]

For purposes of the present analysis, three sets of assumptions on the breakdown of wireless capex are made. In the most detailed scenario, it is assumed that capex is spent on the complete range of items from radio equipment on the towers to the additional equipment needed to upgrade the backend and wired network to handle the increased traffic, as well as on construction and engineering services for network design. The exact percentages of—and the rationale for—the capex breakdown are in the appendix. For comparison, two starkly different sets of assumptions are also employed for comparison. The first adopts the assumptions of Sosa and Van Audenrode (2011) that capex goes to wireless communications equipment in proportion to industry figures for capex and the rest to construction.[14] Their method applied to the latest data results in the assumptions that 31% of wireless capex is spent on wireless equipment and 69% on construction.[15] The other approach adopts the assumptions of Crandall and Singer (2010) and Eisenach et al. (2009) that 7% of spending is on construction and the rest is on wireless communications equipment.[16]

The resulting multipliers for capex were computed from the BEA Regional Input-Output Modeling System (RIMS II), where the region of analysis was the mainland United States and the latest version of the data available are used (the 2007 benchmark input-output table for the nation and 2013 regional data). Since the input-output tables pertain to purchases of domestic goods, the multipliers must be adjusted downward to account for imports of some of the manufactured wireless communications and other equipment.[17]

The results for the main assumptions, shown in Table 1, indicate that every dollar spent on wireless capex creates $1.2 of output across the domestic economy when accounting only for direct and indirect effects (the Type I effects). After including the induced effects of additional household spending, the increase in output rises to $2.1 (the Type II multiplier). The increment to GDP (from the value-added multiplier) is $0.7 for the Type I multiplier,[18] but rises to $1.1 per dollar of

[13] The particular commodities/industries are detailed in the appendix.

[14] That is, they calculate wireless communications capex in the United States as a fraction of total capex, and assume that an additional capex dollar will spend on wireless equipment in the same proportion.

[15] Sosa and Van Audenrode (2011) arrived at the figures of 44% for equipment and 56% for construction with their earlier years of capex data.

[16] Discussion with an industry economist suggested that assuming such a small portion of capex going to construction is unrealistic. Nevertheless, the figures derived from this assumption are presented for continuity with and comparison to those previous studies.

[17] Details of the adjustment are in the appendix. Since the previous studies appear not to have adjusted their figures for import leakages, the multipliers in Table 1 appear to be more modest than those in some of the previous studies.

[18] Type I value-added multipliers are always less than one by the nature of the input-output tables constructed by the BEA. Only a dollar was ultimately spent and the value-added methodology does not double count any expenditure as outputs from one industry are used as inputs in another. Total value

Table 1: Final Demand Multipliers for Mobile Broadband Investment

		Main Assumptions		Alternate Assumptions 1		Alternate Assumptions 2	
Multiplier	Unit note	Type I	Type II	Type I	Type II	Type I	Type II
Output	(1)	1.2	2.1	1.3	2.3	0.6	1.0
Value added	(1)	0.7	1.1	0.7	1.3	0.4	0.6
Earnings	(1)	0.4	0.7	0.5	0.8	0.2	0.3
Employment	(2)	7.5	14.0	9.6	17.4	3.2	6.1

Unit notes: (1) Total dollars per dollar of capex. (2) Jobs per million dollars of capex.
Table notes: Type I effects include direct and indirect effects of investment spending. Type II effects include, in addition, the induced impacts from the additional household spending of workers with increased earnings. See the appendix for the methodology.

capex once the induced effects are included. The additional economic activity from a dollar of capex leads to $0.4 of additional household earnings for workers from direct and indirect effects, and a Type II multiplier of 0.7. Every million dollars spent in capex creates 7.5 jobs in America from the Type I multiplier, rising to 14.0 jobs per million spent from the Type II multiplier.

The economic impacts for output, value added, and household earnings are not very sensitive to whether the main or the first alternate assumptions are used; the results from the alternate assumptions are quite similar. The second set of alternate assumptions lead to much smaller multipliers for each type of impact considered. The large differences with the main set of assumptions arises because nearly all the money is spent on wireless equipment under these assumptions, and a large amount of such equipment is imported. Larger differences among the results appear for the employment estimates. The Type II multiplier for employment is 14.0 with the main assumptions but ranges from 6.1 to 17.4 with the alternate assumptions..[19]

These multipliers for mobile broadband investment are also the economic opportunity costs when such investment does *not* take place. Thus, each dollar not invested can pull more than a dollar out of the economy, whether measured by sales or GDP, reduces earnings, and prevent jobs from being created. The total scale of the opportunity costs created by current policy toward mobile data roaming is estimated in section III.B.3 below.

added sums to less than one because of imports and other leakages.

[19] The larger variance among the outcomes arises because construction is highly labor intensive (at least compared to the equipment manufacturing industries used in the calculations) and the proportion of spending going toward construction varies greatly among the alternate assumptions.

III. Analysis of the poor incentives to invest fostered by current policy

This section discusses the disincentives created by access regulation in general (in part A) and mobile data roaming in particular (Part B). The section concludes with a quantification of the economic harm caused by policy toward mobile data roaming.

A. Telecommunications policy and investment

Infrastructure investment is highly sensitive to changes in telecommunications policy and uncertainty about how committed regulators are to the status quo. Economic investment depends crucially on an expectation of a healthy return on the capital expenditure. Regulators cannot take continued investment and the robust health of the telecommunications infrastructure for granted. The basic economic theory behind the proposition is straightforward. Businesses undertake investment activity only if they expect to earn a rate of return high enough to cover the risks involved and other opportunity costs of capital. Some potential investment projects will be near the break-even point, so that even small adverse changes in risk or other costs can make them unprofitable. Regulatory policy that raises investment or innovation costs, lowers revenue or pushes it farther into the future, or increases business risk will push these marginally profitable potential projects into the red, so that businesses will not pursue these opportunities. While the resulting social cost of such misguided regulation does not show up in any accountant's ledger, the negative impact on consumers and firms is nonetheless real.

A sizeable literature by economists and others documents how communications investment and innovation can be choked off by poor policy (Prieger and Heil, 2008; Cambini and Jiang, 2009). In the review of the literature here, only peer-reviewed research published in academic books and journals is included, to exclude industry-sponsored research that may not have survived peer review. One analysis examined the rate at which new communications services were introduced by regulated firms during a period when the FCC experimented with lighter regulation. The study found that the number of services created during the period of lighter regulation was 60-99 percent higher than the model predicted if stricter regulation had remained in place (Prieger, 2002). A similar study examining state-level data found that when lighter-touch state regulation was applied the incumbent telecommunications company in Indiana in the 1990s, it created new services 2 to 4.5 times faster than it did under a previous, more-restrictive regime (Prieger, 2001).

Other studies compare regulatory regimes to quantify how regulatory stringency dampens investment and innovation in telecommunications. Ai and Sappington (2002) show that state regulatory regimes in the United States that allowed telecommunications providers more leeway in setting their prices induced investment in process innovation that lowered operating costs. Prieger (2007) demonstrates empirically that shorter regulatory delay in offering new telecommunications services leads to quicker product innovation; in other words, there is a "delay multiplier" effect from poor regulation. Another strand of the literature focuses specifically on broadband. Assessing the impact of differences in state regulation, Prieger and Lee (2008) find that the evidence is consistent with stricter regulation (rate of return regulation, in this case) dampening the incentive to deploy broadband infrastructure and service, compared to alternative, lighter-touch regulation.

More recent literature addresses the impact of liberal policies toward service-based competition—i.e., access regulation—instead of encouraging and relying on infrastructure-based competition. One recent study summarizes the current state of knowledge: "the majority of the empirical literature suggests that infrastructure-based competition has a positive impact on both investment and penetration. In turn, the evidence regarding service-based competition relying on broadband access regulations tends to be *negatively* related to investment activities…." (Briglauer, 2014, p.54, emphasis added). Whether studies examine broadband deployment in the United States (Jung et al., 2008) or Europe (Hausman & Sidak, 2005; Wallsten & Hausladen, 2009; Grajek & Röller, 2012; Briglauer, Ecker, & Gugler, 2013), they find that mandated access regulation (of which mobile data roaming is an example) leads to lower investment in and less deployment of next-generation networks. As one of these studies concludes: "promoting market entry by means of regulated access undermines incentives to invest in facilities-based competition" (Grajek & Röller, 2012, p.189). Given the many sources of data, varying methodology, and competing interests motivating the research, not every study comes to the same conclusion. However, as a comprehensive survey of the empirical literature concluded, "…most of the evidence shows that local loop unbundling based on forward-looking cost methodology discourages both ILECs and CLECs from investing in networks" (Cambini & Jiang, 2009).

Mandating access to facilities deployed by rivals also has been shown by some studies to be less effective than facilities-based competition at encouraging broadband adoption by consumers, or to discourage it outright. Again, some studies look at America (Denni and Gruber, 2007) while others cover Europe (Cava-Ferreruela and Albau-Munoz, 2006; Distaso, Lupi, and Manenti, 2006; Höffler, 2007; Bouckaert et al., 2010). There is less unanimity in the literature regarding the impact of access regulation on broadband diffusion than on investment. Yet, in general, the findings from these studies are that infrastructure-based competition has a significant positive impact on broadband penetration, while access regulation and unbundling is less important or has no effect—or even a negative effect—on the spread of broadband Internet access.

To think about why access regulation may hinder broadband adoption, consider the case of mobile roaming. When a carrier relies on roaming to serve customers in a rural area, it is unlikely to sign customers onto its network who live in that area.[20] Thus consumers there will not enjoy the benefits of the added competition—lower prices, higher network quality, etc.—that facilities-based

[20] Instead, the roaming will be for the convenience of its subscribers in other areas in which it has its own network coverage, for when they roam outside their home areas.

entry would entail, and some of them may find the value proposition unattractive enough to stay off the network.

Proponents of access regulation often justify it based on the so-called "stepping-stone" or "ladder-of-investment" (LOI) theory. The LOI approach claims that service-based competition (when entrants lease access to incumbents' facilities) serves as the bottom rungs of a ladder ascending to facility-based entry. The theory may be attractive to regulators trying to stimulate competition in markets by artificially creating competitors who have not entered the market in the traditional sense by investing in their own infrastructure. Notwithstanding the appeal, there is little empirical support for LOI theory. Most of the empirical work draws on data from Europe, where telecommunications regulators have explicitly adopted the LOI framework. Bacache, Bourreau, and Gaudin (2014) show in a careful econometric study of the European experience that there is no empirical support for the LOI hypothesis. Firms entering only by means of mandated access to rivals' network did not transition toward infrastructure-based competition.

B. Policy toward data roaming in the United States

1. Public policy regarding roaming

Roaming in the mobile communications industry refers to the process by which one wireless provider uses another provider's network to serve its customers. Roaming allows a carrier's customers to travel out of its home territory (the areas it has deployed its network) but still be able to complete mobile calls and enjoy broadband access. Roaming has been around for as long as the mobile voice industry, and at first relied on private contractual arrangements between carriers. The FCC first established rules in favor of roaming in 2007 for voice communication, requiring host providers to "automatically" allow access to any carrier agreeing to reasonable terms and conditions (FCC, 2015b). In 2010, the FCC eliminated the home market rule, which had stipulated that if a provider owned spectrum covering an area it could not demand roaming from other providers there. The sound economic logic behind the home market rule was that the option to rely on roaming should not serve to discourage facilities-based network competition, when the spectrum is licensed and readily available for use.

In April 2011, the FCC issued its first set of rules specifically for mobile data roaming (FCC, 2011a). Under these rules, the obligation of a host provider to automatically allow roaming on its network was extended to data service. The rules require facilities-based service providers of mobile broadband to offer data roaming arrangements to other providers on "commercially reasonable terms and conditions." In its order, the FCC concluded that the data roaming rules would "promote consumer access to seamless mobile data coverage nationwide, appropriately balance the incentives for new entrants and incumbent providers to invest in and deploy advanced networks across the country, and foster competition among multiple providers in the industry...." (FCC, 2011a, at 13). In other words, the FCC relied upon the ladder of investment (LOI) theory to justify its access regulation, despite the empirical literature reviewed above either questioning whether it leads to those rosy outcomes or demonstrating that it does not.

In May 2014, T-Mobile USA petitioned the FCC to provide guidance on what "commercially reasonable" should mean in practice and on what role the extent of build-out should play in the determination. In December 2014, the FCC granted three specific requests made by T-Mobile in its Declaratory Ruling (FCC, 2014b). While the details are complex, the general result of the new rules is that mobile data roaming becomes cheaper and easier for requesting providers. First, the FCC set forth several benchmarks by which to assess whether proposed data roaming rates are reasonable: retail rates, international roaming rates, MVNO/resale rates, and other domestic roaming rates (despite the fact that the technology, geography, and other cost factors underlying these other rates may have been completely different), any or all of which may be considered on a per-case basis. Second, the FCC removed the presumption that a past data roaming agreement is reasonable when negotiating the next agreement. Third, the host provider was disallowed from denying roaming services to a requesting provider on the basis that the otherwise built-out requesting provider had not built out in the particular area at issue.

AT&T and Verizon have filed petitions with the FCC contesting the new interpretations of the original data roaming order; the FCC is currently considering those requests that its latest guidelines be reviewed (Goldstein, 2015). Some of the carriers' objections are procedural in nature, arguing that the FCC effectively changed regulations without an actual proceeding for a rulemaking. Another objection made is that by recasting the test for commercial reasonableness as something to be determined by the FCC on a case-by-case basis, the regulator has imposed a vague standard—actually, a *non*-standard—leading to unpredictable outcomes. Vagueness can lead to arbitrary decisions regarding the terms and rates for roaming agreements; as discussed above uncertainty of outcomes is likely to discourage investment on both sides.[21] The main economic concern is related to the theory and empirical evidence regarding access regulation discussed above: allowing roaming discourages mobile service providers to expand their own coverage and invest in building out wireless infrastructure.

2. Negative consequences of the policy in general

The review of the literature above indicated that access regulation in general leads to the (entirely predictable) consequence that facilities-based competition and investment is retarded. With specific reference to data roaming, it is easy to see the perverse incentives the current rules provide. Allowing non-investing carriers to interconnect their mobile data customers in rural areas to their rivals' networks at advantaged rates throws water on the fire to deploy their own infrastructure. Consumers lose out on at least two benefits. First, research by Prieger, Molnar, and Savage (2014) shows that competition using facilities-based

[21] Economic theory—as well as common business sense—has long made it clear that regulatory uncertainty prevents or delays private investment. Dixit and Pindyck (1994) show formally how uncertainty creates an option value for the would-be investor to wait until the uncertainty is lessened or resolved. Teisberg (1993) shows that firms invest less and delay investment when faced with uncertain outcomes created by regulation.

infrastructure spurs providers to improve the speed of broadband. While their results were estimated using data from the wired broadband market, the same principle can apply to wireless. Clearly a data roaming provider cannot offer higher speeds to its subscribers if it is not deploying the infrastructure to do so. Without this competitive impetus, the host roaming provider also misses out on the additional incentive to upgrade its facilities. Furthermore, despite the spectrum crunch, licensed bandwidth lies fallow, since the roaming carrier typically uses (and therefore congests) the host provider's spectrum, not its own.[22]

Second, reliance on data roaming for rural areas in many cases will not expand competitive options for rural residents. If a person lives in an area covered by a spectrum license held by a provider which has not built out in that area, it is unlikely that the provider would allow the user to sign up for mobile broadband service. Instead, the data roaming is typically offered instead as a convenience to subscribers from other (more urbanized) areas who are traveling. For example, as noted by AT&T (Marsh, 2014), T-Mobile holds spectrum licenses covering the United States but does not in fact (based on its coverage maps from the time) offer service in many rural areas in the Midwest, Mountain, and certain Eastern portions of the U.S. In a separate analysis of the largely rural states of Montana, New Mexico, North Dakota, South Dakota, and Wyoming, Smith (2015) finds that Sprint and T-Mobile hold spectrum licenses in each county in each state, but provide neither voice nor data service in 77% of those counties. In contrast, AT&T and Verizon, the main host roaming providers in those states, each offer mobile voice and data service in almost all counties.[23]

Under the 2014 Declaratory Ruling, the host provider is not allowed to denying data roaming services to a competitor on the basis that the requesting provider has not deployed its own infrastructure in the area even when it has built out in other areas. Through its decision, the FCC in essence gives non-investing mobile broadband providers license to ignore at least the intent of the buildout requirements inherent in the ownership of spectrum licenses. The purposes of the buildout requirements are to encourage licensees to provide facilities-based service in a timely manner, to prevent the "warehousing" of spectrum (obtaining licenses merely to prevent rivals from having it), to promote the provision of innovative services throughout the license areas, and to encourage provision of service in rural areas (GAO, 2014).

The letter of the law regarding the buildout requirements for spectrum holdings is quite involved, and varies by type of license (the geography, spectrum band, and wireless services authorized). The requirements themselves vary with regard to how buildout is measured (e.g., fraction of population or area), whether there is just one or multiple

[22] in the case of Sprint and T-Mobile, the companies nearly always holds licensed spectrum in the areas it instead relies upon roaming, as discussed in the next paragraph.

[23] AT&T and Verizon offer mobile data coverage in at least parts of more than 99.5% of the counties in these five states (although not every part of every county is covered in some cases). Refer to the coverage maps and Appendix A in Smith (2015).

milestones for coverage to be met, and how much time after acquisition of the license is granted to meet the goals.[24] Given the complexity of the requirements and the fact that virtually the only entity that could verify whether they are met is the license holder itself—which is why the FCC relies on self-certification to "enforce" buildout requirements for wireless services—it is beyond the scope of this report to assess whether buildout in any particular area has been met. The spirit of the rules, however, is clear from the goals: to provide service and an expanded set of competitive choices to consumers, especially in rural areas, in a timely manner.[25]

Thus, an obligation to offer data roaming "automatically" to rivals provides clear disincentives to invest in network-based competition. There is even some evidence that roaming has spurred some *disinvestment* in the past. In some cases Sprint has told subscribers in particular areas that it was switching to roaming when it had formerly provided coverage using its own network.[26]

3. An estimate of the scale of the negative economic impacts

In the United States today, there are four major, national providers of mobile broadband service: AT&T, Sprint, T-Mobile, and Verizon. Each holds spectrum licenses to offer mobile wireless voice and data services in almost all parts of the country. However, only two of those providers, AT&T and Verizon, have both committed to and achieved deploying the infrastructure needed to serve latest-generation mobile broadband to most of rural America. The latest report from the FCC on the mobile communications market shows that the LTE networks for mobile broadband of AT&T and Verizon cover 85% and 92%, respectively, of rural population in the United States. On the other hand, Sprint and T-Mobile each cover less than half of the rural population with their LTE networks. The stark differences in rural coverage are shown in Figure 1.[27]

Building infrastructure in rural areas requires large investments. Figure 2 shows the wireless capex in recent years of the four national mobile broadband providers.[28] AT&T and

[24] Refer to GAO, 2014, for an explication and review of the FCC's build-out requirements.

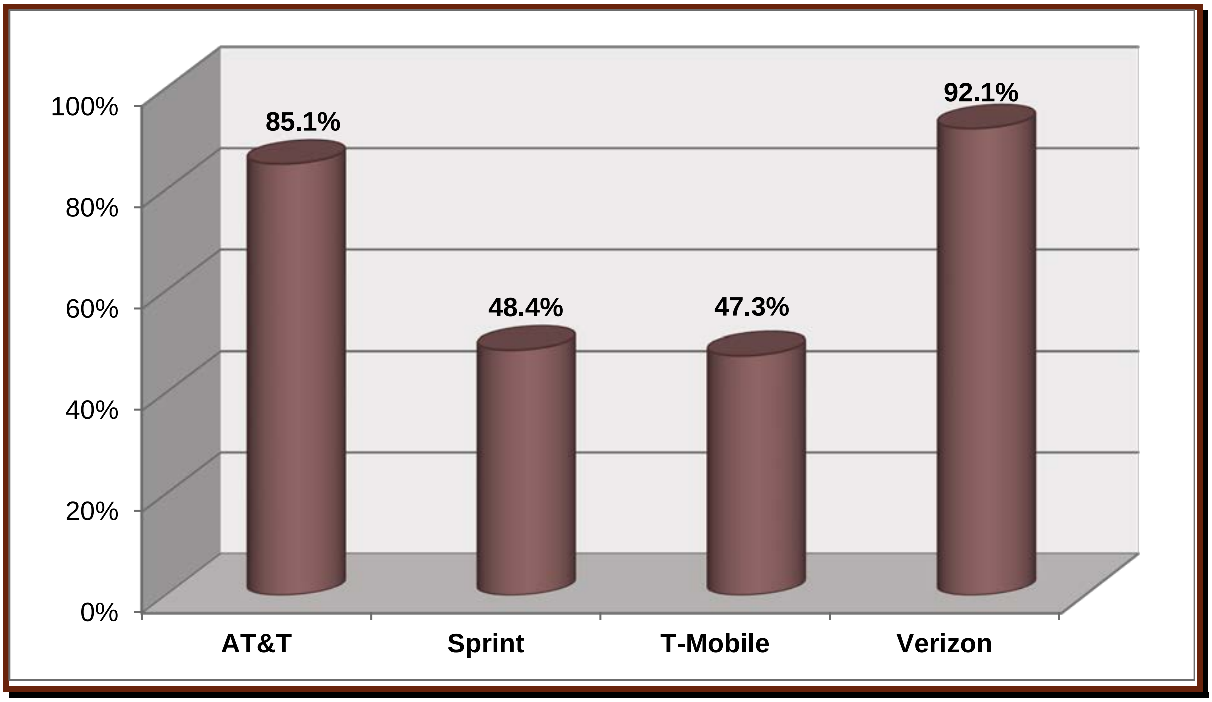
[25] The FCC had an interesting notion to offer in (oblique) response to such criticisms. In the Declaratory Ruling, the FCC (2014b) stated that is some areas "it is uneconomical for several providers to buildout." The obvious question one then must ask is: why did they sell multiple spectrum licenses for such areas? The rationale for selling multiple licenses in each area was, on the one hand, that technology and the scale of consumer demand had changed drastically enough since the 1980s that wireless communications was no longer a natural monopoly or duopoly in which provision by only one or two providers was most efficient. On the other hand, multiple licenses were offered in recognition of the benefits to consumers of vigorous facilities-based competition among providers.

[26] Quinn (2012a,b) documents (from Sprint's announcements and coverage maps provided to customers) one such episode in Kansas and Oklahoma in 2012, which Sprint openly described as a "cost-cutting measure." Sprint also told investors that reliance on roaming instead of deploying infrastructure had led the company to spend $15 billion less in capex from 2008 to 2011 than it otherwise would have (Sprint Nextel [2012], quoted and discussed in Quinn [2012c]).

[27] Note that the FCC states that their calculations likely result in an overstatement of the extent of mobile wireless coverage.

[28] An industry economist pointed out that these wireless capex figures underestimate the true deployment costs of mobile broadband, since wireless communications often depends on wired backhaul. However, backhaul fees paid to wireline appear as

Figure 1: Estimated Mobile LTE Coverage in Rural Areas by Service Provider, July 2015



Source: FCC, 2015b.

Verizon have invested more than twice as much as Sprint and T-Mobile since 2011.[29] Of course, not all capex during these years went to rural broadband; providers were also adding bandwidth and improving facilities in urban areas as well. However, much did go toward building out in less urban and rural areas. Since 2012, AT&T has more than doubled its LTE broadband coverage (in terms of population covered), from 150 million people covered in November 2012 to over 300 million covered today (FCC, 2013, 2015b). Verizon increased its LTE broadband coverage from 200 million people covered in November 2012 to over 300 million today. Both AT&T and Verizon now cover about 97% of the total population in the nation as of July 2015, per analysis by the FCC (2015b). Sprint and T-Mobile, while improving their LTE coverage over the years, still do not offer the latest generation of mobile broadband to 15% of Americans, mostly in rural areas.[30]

Without the data roaming rules, either in the original form from the 2011 Order or the modified form from the 2014 Declaratory

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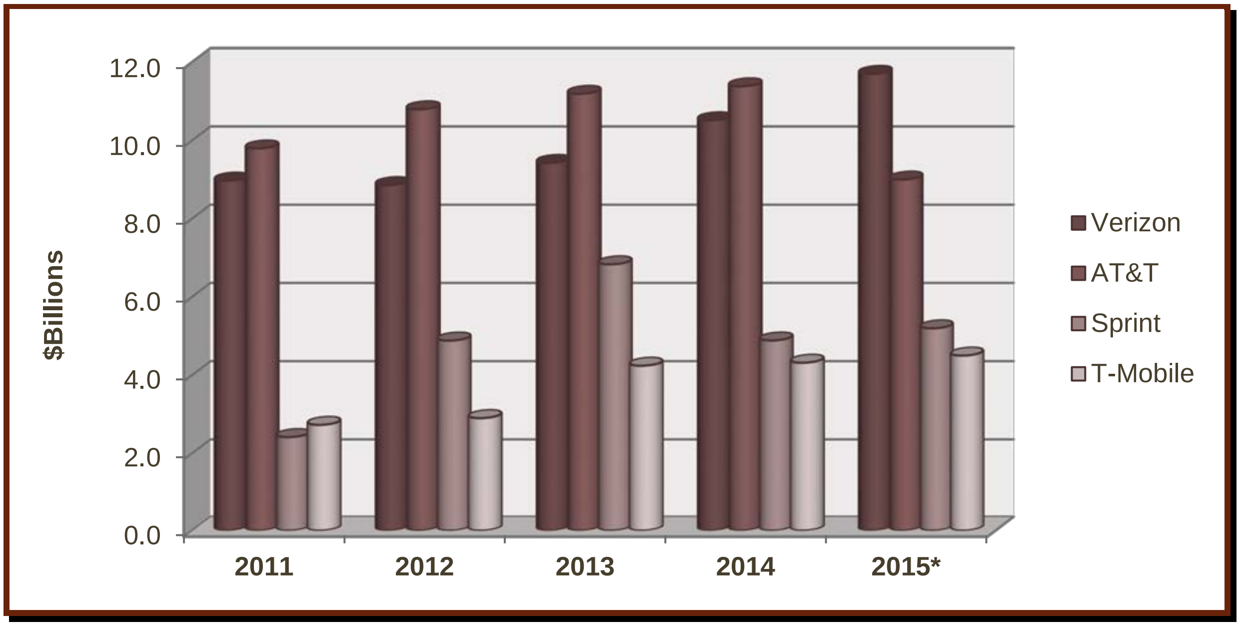
operating expenses for the wireless carrier or division, not capex.

[29] AT&T and Verizon invested $101.6B in wireless capex during these years, while Sprint and T-Mobile USA invested $43.1B. The former figure is 136% more than the latter figure.

[30] The FCC (2015b) calculates that AT&T covers 302.1 million of the 312.5 million people in the nation with its LTE mobile broadband network, and that Verizon covers 303.2 million. Sprint covers 265.6 million and T-Mobile covers 266.2 million people, although it is unclear from the FCC report whether those figures include the LTE roaming areas of the two carriers.

Figure 2: Wireless Capital Expenditure by Major Providers, 2011-2015



Note: Data for AT&T and Sprint for 2015 are estimated. Sources: FCC (2015b), Verizon Communications (2016), Raymond James Financial (Louthan, 2015), Skyline Marketing Group (Celentano, 2015), and T-Mobile US (2016).

Ruling, what would investment look like for Sprint and T-Mobile? Analyzing a counterfactual is always difficult, because—by definition—the object of study is not observed directly. And, while economists in the field of industrial organization have made great econometric strides in recent decades toward estimating an industry's response to counterfactual situations, the detailed data needed for such techniques are unavailable here. Therefore instead of performing a formal econometric analysis, a more informal—yet still illuminating—procedure is adopted here.

If Sprint and T-Mobile could not rely on data roaming to extend their coverage areas, or could only do so for a brief time while they deployed their own infrastructure, then to offer LTE coverage comparable to AT&T and Verizon they would each have to have covered about 37 million additional people with their networks as of midyear 2015.[31] The bulk of these people without coverage—24 million of them—are in rural areas. To be conservative, only these rural Americans not covered by Sprint and T-Mobile will be included in the analysis.

How much investment would it have taken to cover these additional people? Wireless broadband deployment costs per head covered vary hugely in the estimates of academics, industry, and business analysts. At the extreme low end, one source in the trade press refers to figures purportedly from a major carrier indicating that it would cost $69 per head covered to push mobile broadband

[31] This figure is based on the LTE coverage figures in the previous footnote.

out to 55 million rural inhabitants.[32] This figure would be for a "brownfield" deployment of LTE where previous generation mobile networks are already deployed. Bazelon (2010) estimates that the capex required for greenfield fixed wireless broadband for a particular rural county is $219 per household,[33] which would be about $85 per person. Fixed wireless costs are typically lower than mobile broadband costs, due to the lower spectral efficiency expected with mobile communications. Other sources for remote rural areas with difficult terrain and extremely sparse population arrive at coverage costs around $1,000 per subscriber.[34]

For another source of mobile wireless deployment costs, consider the reverse auctions the FCC conducted for the Connect America Mobility Fund.[35] In these auctions, the FCC designated a set of unserved areas for bidding and providers bid on the minimum one-time support payment they would accept in exchange for deploying 3G (or better) mobile service to the area. If the auctions served as an effective information-revelation device, the winning bids would be roughly the same as the deployment cost.[36] The distribution of the 483 winning bids for areas in the mainland U.S., expressed as dollars per population living in the area covered, is shown in Figure 3. The range of implied deployment cost per head is huge: the interquartile range stretches from $433 per capita to $4,459. The median winning bid was $1,453 and the average was $1,381 (both per capita.)

Given the variety of figures presented here, reasonable and conservative estimates for the capital expenditure necessary to deploy LTE would appear to be in the range of roughly $100 to $1,400 per person.[37] The analysis here proceeds by adopting a conservative figure near the low end of these estimates: $200 of capex required per person covered. As a final point of comparison, the $200 per

[32] See RWA (2011). The organization claims that in a temporarily unredacted filing to the FCC, AT&T stated that incremental rural LTE deployment could be extended to 55 million mostly rural Americans for $3.8 billion. Dividing the latter figure by the former yields $69.09 per head. Neither the claim nor the context of the statements can be verified at the present time.

[33] This figure excludes cost for the spectrum license.

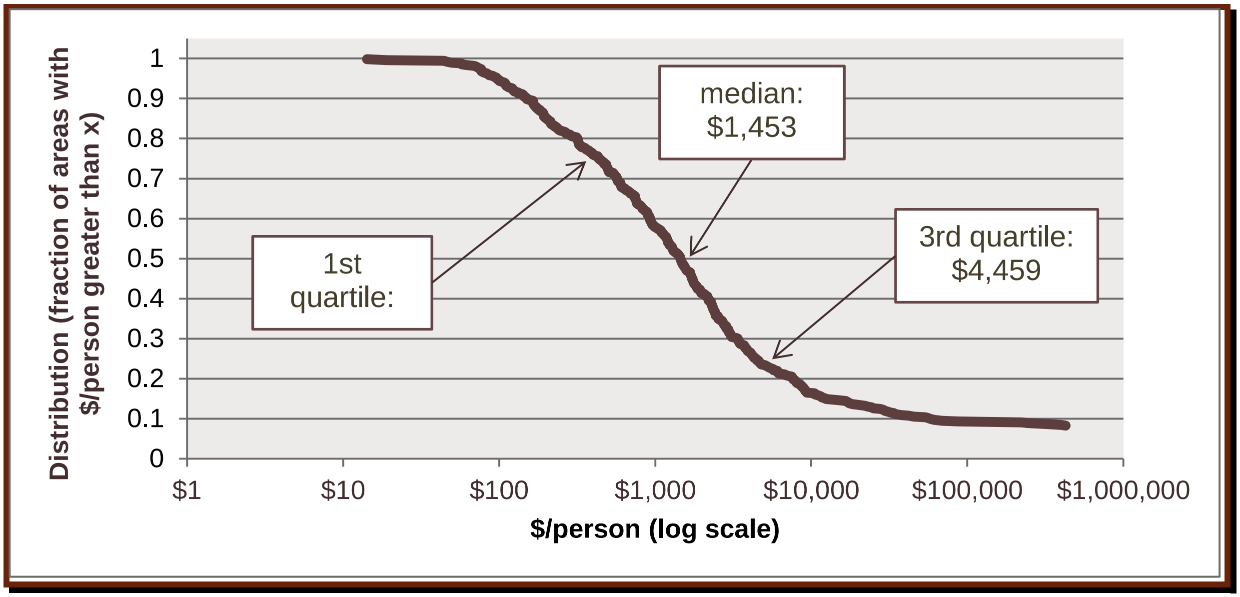
[34] One cost estimate for a small (120 subscriber) rural cell site came to a total of $107,000 for the tower site, necessary studies, equipment, and backhaul (Yurok Tribe Information Services Department, 2011). Those figures amount to about $890 per subscriber. Another study for fixed wireless broadband provision in Wyoming arrived at a figure of $1,243 up front capital cost per customer. Deployment of fixed wireless broadband is typically less expensive than mobile broadband, since the fixed equipment does not need to handle the complications that arise from mobility such as handoff between cell sites and impairment of mobile channels with interference, multipath, and blockage, all of which are highly spatially and temporally variable (Bergman, 2014).

[35] Details on Phase I of the Mobility Fund are in FCC (2011b), at 301-478.

[36] Auction theory suggests that bids would be the difference between the present value of the expected revenue stream on the one hand and the deployment cost plus the expected stream of operating costs on the other hand (or, more precisely, the winning bid would be a bit below the second-lowest such difference, with the carrier with the lowest such difference winning the auction). Assuming that mobile service would be priced high enough to cover operating costs in these areas, the difference reduces to the deployment cost. The bids were placed in 2012 and have not been adjusted for inflation here.

[37] The low end of the range comes from Bazelon's fixed wireless deployment estimate of $85/head discussed above, marked up to account for the lower efficiency of mobile broadband and inflation since 2010. The high end of this conservative range is around the mean and median of the Mobility Fund winning bids discussed in the text.

Figure 3: Support per Capita for Mobile Network Deployment Derived from the FCC Mobility Fund Auction



Source: Data on population per area are from the Biddable Items list for Auction 901 (wireless.fcc.gov/auctions/901/901_biddable_items_090712.xls); the winning bids are from the FCC Results page for Auction 901 (auctionsignon.fcc.gov/signon/index.htm); the implied $/person are calculated by the author. The 483 bids are for areas in the mainland U.S. only.

head assumed here is much less than the $413 per subscriber offered as high-cost support under the FCC's Connect America Fund for areas unserved by broadband.[38]

These figures imply that in a counterfactual world without Sprint and T-Mobile being able to rely indefinitely on data roaming in rural areas, and in which the two providers take seriously the intent of their buildout obligation, there would have been an additional **$9.6 billion** in wireless investment in recent years.[39] This amount is the total across both companies.[40] Note that this

[38] Phase II of the Connect America Fund employed an economic-engineering cost model to identify high-cost areas lacking competition. The total CAF II funding offered across the nation was about $1.5 billion to cover 3.6 million mostly rural homes and businesses. The implied $413 per subscriber includes operating expenditure and not just capex, but on the other hand it only includes a year's worth of amortization of the capex. The number is also lowered compared to the other estimates of capex/head because 1) business locations are included in the denominator, 2) it is an amount to be offered as supplemental support, not the actual full yearly cost of providing service, and 3) it is for fixed broadband, not mobile.

[39] The figure is the result of multiplying $200 capex per head by 24 million people by two carriers: 200 × 24 million × 2 = 9.6 billion.

[40] A possible objection to the calculations may be that if Sprint and T-Mobile had spent the additional $3.8 billion to extend their rural coverage that they would have spent less in other areas. This appears to be unlikely. If it was profitable to undertake the other investment that actually occurred, the additional spending postulated here does not change that fact. Companies seek profitable investment projects and then raise funding for them (whether internally or by going to debt or equity markets); basic microeconomics teaches that unlike households, firms

amount of spending is still less than the difference in capex in any single year between these firms on the one hand and AT&T and Verizon on the other, as can be derived from Figure 2. The amount, while not small, appears to have been within the capabilities of the firms to have spent had they not been able to rely of roaming.[41]

What impact did that forgone investment have on the economy? Multiplying the $9.6 billion in forgone capex by the multipliers calculated in section II.B above yields the outcomes in Table 2. Under the main set of assumptions, the Type I effects show that the economy lost out on $11.7 billion in additional sales that would have added $6.4 billion to GDP. Forgone earnings total $4.0 billion, while about 71,500 new jobs would have been created but were not. Under the alternative assumptions described above, additional output not created ranges from $6.2 billion to $12.6 billion and value-not-added ranges from $3.5 billion to $7.0 billion. The figures for earnings and employment have similarly broad ranges. However, even the low end of the estimates—lost incremental earnings of $1.8 billion and about 30,500 jobs—are sizeable economic impacts on the labor market. The high end of the estimates includes incremental earnings of $4.8 billion prevented from entering the pockets of workers and about 91,900 positions never created.

The Type I economic effects stop short of tracing out all the impacts of the changes in the economy due to the spending since they do not include the induced effects from the additional household spending of workers. The Type II effects, included on the right side of Table 2, show that the forgone investment from reliance on data roaming led to much larger final economic impacts than the Type I effects capture. Under the main set of assumptions, the Type II effects indicate that if Sprint and T-Mobile would have spent the additional $9.6 billion in capex, there would have been $19.8 billion in additional sales in the American economy, adding $10.9 billion to GDP. Earnings would have increased by $6.4 billion, while about 134,100 new jobs would have been created. Under the alternative assumptions, as much as $22.2 billion in additional sales would have ensued and as much as $12.4 billion of value would have been added to the economy. The low end of the estimates include $2.9 billion for additional earnings and 58,500 jobs, while the high-end estimates are incremental earnings of $7.6 billion and about 166,600 new positions. All of this additional

do not begin their economic decision-making with a budget constraint.

[41] It appears that spending an additional $9.6 billion in total would have been well within the capabilities of the firms. If Sprint would have spent the same proportion of capex to service revenue in 2010-2012 that it did in 2013, it could have spent $10.5 billion more in those years—more than necessary to make up its half of the $9.6 billion in additional capex underlying the estimates above. Thus, based on Sprint's 2013 level of capex, there is no indication that the additional investment amounts discussed here would have strained the company's financial capacities. The same calculation for T-Mobile USA implies the company could have spent $2.8 billion more on capex during 2010–2012. This is less than the $4.8 billion making up T-Mobile's half of the additional capex discussed here. However, if the additional amount were spread evenly among 2010–2012, it would be a 55% to 59% increase over actual capex in those years. T-Mobile in fact raised its capex by 51% in 2013 over its average level from the previous three years, with no apparent financial strain on the company or degradation of its stock price. The capex and service revenue estimates used in these calculations come from FCC (2015b).

Table 2: Economic Benefits Forgone Due to Reliance on Mobile Data Roaming Instead of Investment in Infrastructure

	Type I Effects		Type II Effects	
Final-Demand Multiplier	Main Assumptions	Alternative Assumptions	Main Assumptions	Alternative Assumptions
Output ($B)	11.7	6.2 – 12.6	19.8	9.8 – 22.2
Value added ($B)	6.4	3.5 – 7.0	10.9	5.6 – 12.4
Earnings ($B)	4.0	1.8 – 4.8	6.4	2.9 – 7.6
Employment (# jobs)	71,531	30,467 – 91,888	134,122	58,454 – 166,630

Notes: Impacts are based on $9.6 billion additional investment in wireless capex. Type I effects include direct and indirect effects of investment spending. Type II effects include, in addition, the induced impacts from the additional household spending of workers with increased earnings.

economic activity would have been most welcome in the generally weak economy and labor market since the recent recession.

The estimates here are meant to suggest the possible magnitude of the proximate economic consequences of lax policy toward mobile data roaming. The ultimate consequences for the economy may have been even larger, for two reasons. The estimates in Table 2 do not include "network effects", which arise from the ways that business and consumer behavior and capabilities change due to mobile broadband infrastructure.[42] As discussed above, as a general-purpose technology, mobile broadband infrastructure allows the transformation of existing industries and the creation of new technologies, firms, industries, and ways of using labor that would create extra value for the economy. Second, the calculations are based on expansion of Sprint and T-Mobile's networks to cover additional rural Americans only. If these providers would have also expanded their network coverage in nonrural areas to match AT&T and Verizon, an additional 13 million Americans would have been covered in those regions. Even generously assuming that deployment of LTE in nonrural areas costs only $80 per head (only 40% of the assumed cost for rural areas), covering these additional people would increase all of the benefits from investment shown in Table 2 by between one-fifth and one-quarter.[43]

[42] Atkinson et al. (2009) discuss such network effects in the general context of investment in digital infrastructure.

[43] At $80/head instead of the assumed $200/head for rural coverage, there would have been $80 × 13 million people × 2 carriers = $2.1 billion in additional wireless capex. This spending would add 22% to the $9.6 in capex calculated above for the rural areas, and all the figures in Table 2 would increase by 22%.

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Appendix

This appendix contains some additional detail on the calculation of the multipliers and the final economic impacts discussed in the text.

The main set of assumptions are as follows:

1. In the breakdown of whither goes a dollar of capex, it is assumed that 31% of wireless capex is spent on wireless equipment. This figure is derived from the estimated share of wireless equipment spending to wireless capex for the wireless broadband industry, averaged over 2012-2015 (Credit Suisse, 2014).
2. For that wireless-specific part of the capex, 70% of spending is for radio equipment, 15% is for backhaul, and 15% is for the LTE evolved packet core.[44] These items are linked to data from BEA in the following manner:
    - Radio equipment is associated with BEA commodity 334220, Broadcast and wireless communications equipment.
    - Backhaul is associated with BEA commodity 335920, Communication and energy wire and cable manufacturing (for fiber optic).[45]
    - Evolved packet core expenditures are associated with BEA commodity 334413, Semiconductor and related device manufacturing.[46]
3. For every four dollars spent on the items in numbers 1 and 2 above, another dollar is spent on engineering services. This estimate appears to be conservative; the wireless industry as a whole spends a far greater share on NAICS category 541300, Architectural, engineering, and related services, than on equipment (but the industry requirements table mingles opex and capex).
4. For every four dollars spent on the items in numbers 1-3 above for the wireless-specific part of the capex and associated engineering costs, another dollar is spent upgrading other parts of the wired network to handle the additional traffic. This dollar is spent on additional engineering services, fiber optic cable, and other equipment for the wired broadband network (associated to the same BEA commodities as in number 2 above). The proportions for these three items are the same as for the BEA direct requirements for the wireless communications industry.

[44] A wireless industry analyst is quoted in Mucci (2013) as saying that 70% of wireless capex is devoted to construction, installation, and equipment for the radio component of the network, while the rest goes to construction, installation, and equipment for the backhaul and LTE (i.e., evolved packet core).

[45] Two issues arise with backhaul. First, backhaul in the mobile wireless industry is often purchased from other providers. However, the FCC's most recent industry report states that "the leading mobile wireless service providers have deployed or are in the process of deploying Ethernet backhaul either over fiber or microwave to their cell sites" (FCC, 2015b at 70). In particular, "As of March 2015, of its 54,000 cell sites, T-Mobile already has fiber backhaul connections to 50,000 sites" and "Sprint's network modernization was substantially completed in 2014 which utilizes Ethernet for its backhaul and its LTE network covered more than 280 million people as of May 2015" (FCC, 2015b at 70)

[46] Some of these expenditures may instead be associated with 334210, Telephone apparatus manufacturing, which (despite the old-fashioned sounding name) includes equipment such as routers. However, the industry spends far more on commodity 334413 than on commodity 334210, per the BEA's direct requirements table for the wireless communications industry. The 2007 Direct Requirements table shows that wireless telecommunications carriers (industry 517210) use 5.9 cents worth of commodity 334413 (semiconductors) but only 0.6 cents worth of commodity 334210 (telephone apparatus) to create a dollar's worth of output. Thus, commodity 334413 is chosen. Given the minor differences in the multipliers for semiconductors and telephone apparatus, this decision does not affect the final results much.

5. The remainder of capex goes to construction. The relevant construction category in the BEA commodity/industry tables is 2332C0, Nonresidential structures, which includes category 233240, power and communication structures (among others).

After establishing these assumptions, the next step toward calculating the multipliers is to determine for spending on manufactured goods how much of each dollar goes toward the manufacturer, how much goes to the wholesaler, and how much for transported the manufactured goods.[47] These are known as the distribution costs for the manufactured commodities. Following the accepted methodology provided by BEA results in the following figures: 80% of spending on broadcast and wireless communications equipment goes to the manufacturer, 18% to the wholesale industry, and the trivial remainder goes to transportation. For communication and energy wire and cable manufactured goods, the similar breakdown is 77% to the manufacturer, 22% to wholesale, and 1% to transportation. The same three figures for semiconductor and related device manufactured goods are 82%, 16%, and 1% to the manufacturer, the wholesaler, and transporter, resp.

Next, how much of spending on the manufactured items stays within the domestic economy is determined, versus leaking abroad through the purchase of imported goods. The fraction of domestically produced and delivered goods out of all purchases (domestic + imported) by industry is found from United States Census Bureau's *Manufacturing and International Trade Report: 2013 and 2012*. Matching industries as closely as possible to the BEA categories, the following figures are used: 21% of commodity 334220, 71% of commodity 335920, and 60% of commodity 334413 is domestically produced. The rest of the spending (the part going to imported goods) disappears from the rest of the calculations.

The result of these assumptions and procedures is the final breakdown of a dollar of wireless capex as shown in Table 3. The final column sums to less than 100% due to spending on imported goods.

Table 3: Division of Total Wireless Capex into Its Constituent Domestic Parts

Commodity/Industry	Fraction of wireless capex
Broadcast and wireless communications equipment	5.3%
Communication and energy wire and cable manufacturing	4.0%
Semiconductor and related device manufacturing	7.7%
Architectural, engineering, and related services	15.5%
Construction of Nonresidential structures	30.8%
Transportation	0.7%
Wholesale	9.7%

Note: Figures sum to less than 100% due to leakage to imports.

The Type I and Type II multipliers for each of the rows in the table above were obtained from the BEA RIMS II system, where the region of analysis was the contiguous United States. The 2007 benchmark input-output table for the nation (to calculate linkages among industries) and 2013 regional data (to calculate leakages outside the region) were used; these are the latest available data in RIMS. The multipliers are shown in Table 4 below.

The final multiplier of each type is a weighted sum of the commodity-specific multipliers and the "Fraction of wireless capex" weights in the

[47] The BEA (2013) documentation on the use of the RIMS II multipliers describes this procedure.

previous table above. The final multipliers are given in Table 1 in the text.

For the alternative assumptions, to hew to the methodology of the original authors from which the assumptions are taken, there are no adjustments for distribution costs (transportation and wholesaling). Otherwise the procedure to arrive at the final multipliers in Table 1 is the same as outlined above. In particular, this means that unlike some of the original authors, leakages to imports are still accounted for here.

Table 4: Final Demand Multipliers for Mobile Broadband Investment

BEA/ NAICS	Commodity	Final-demand Output (dollars)	Final-demand Earnings (dollars)	Final-demand Employment (number of jobs/$M)	Final-demand Value-added (dollars)
		Type I Multipliers			
334220	Broadcast and wireless communications equipment	1.59	0.34	4.92	0.83
335920	Communication and energy wire and cable manufacturing	2.24	0.42	7.30	0.70
334413	Semiconductor and related device manufacturing	1.47	0.40	4.92	0.89
541300	Architectural, engineering, and related services	1.73	0.65	11.13	0.93
334210	Telephone apparatus manufacturing	1.69	0.41	5.54	0.84
2332C0	Nonresidential structures	1.65	0.66	12.77	0.91
484000	Truck transportation	1.85	0.55	11.40	0.87
420000	Wholesale trade	1.50	0.48	8.05	0.97
		Type II Multipliers			
334220	Broadcast and wireless communications equipment	2.27	0.54	10.20	1.22
335920	Communication and energy wire and cable manufacturing	3.08	0.67	13.85	1.17
334413	Semiconductor and related device manufacturing	2.27	0.64	11.16	1.34
541300	Architectural, engineering, and related services	3.02	1.03	21.24	1.66
334210	Telephone apparatus manufacturing	2.50	0.65	11.89	1.29
2332C0	Nonresidential structures	2.96	1.04	22.99	1.64
484000	Truck transportation	2.96	0.88	20.00	1.50
420000	Wholesale trade	2.45	0.76	15.49	1.50

Note: The multipliers are from the BEA RIMS II system, where the region of analysis was the contiguous United States. The 2007 benchmark input-output table for the nation and 2013 regional data were used.